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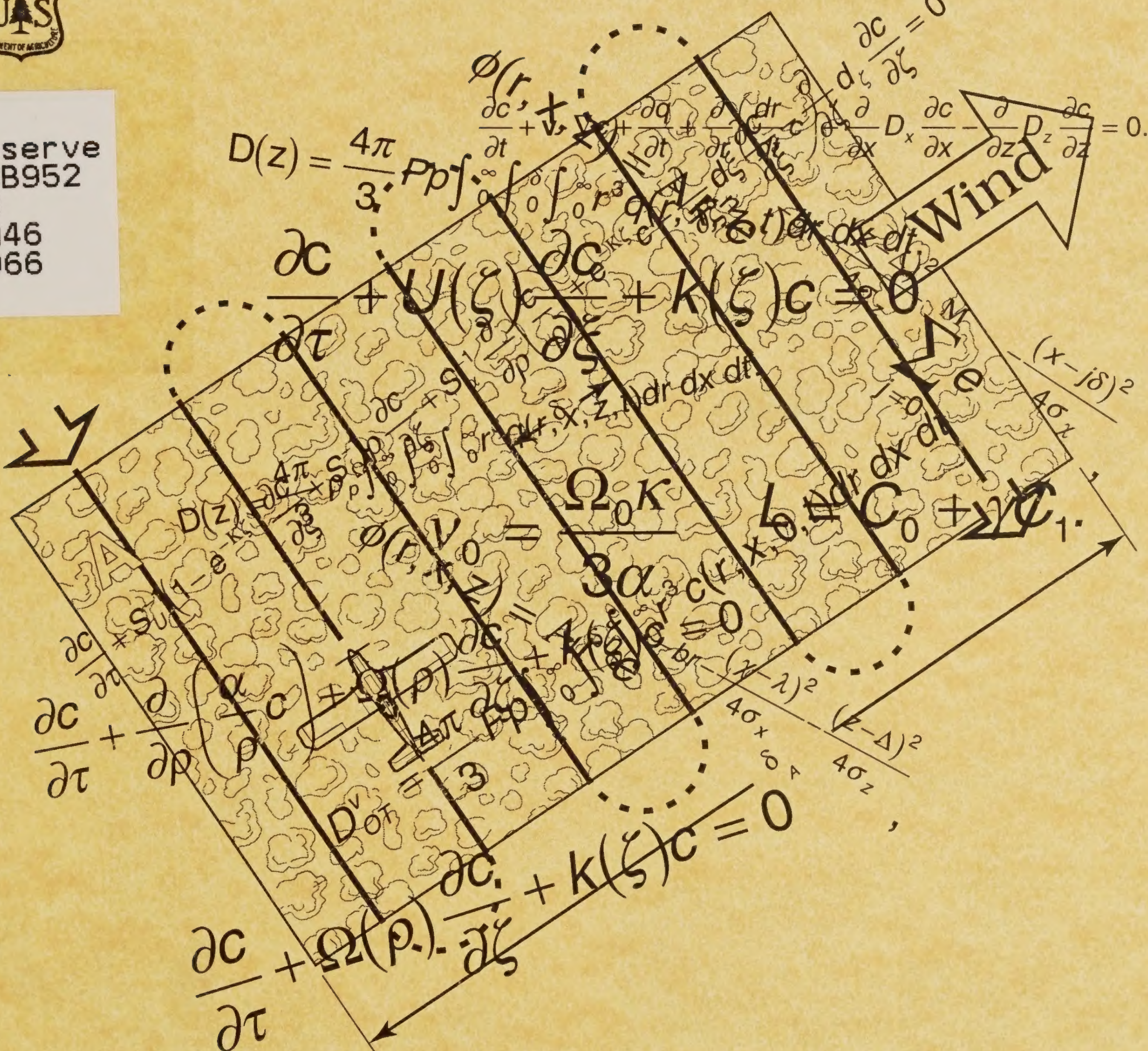
Optimized Pesticide Application



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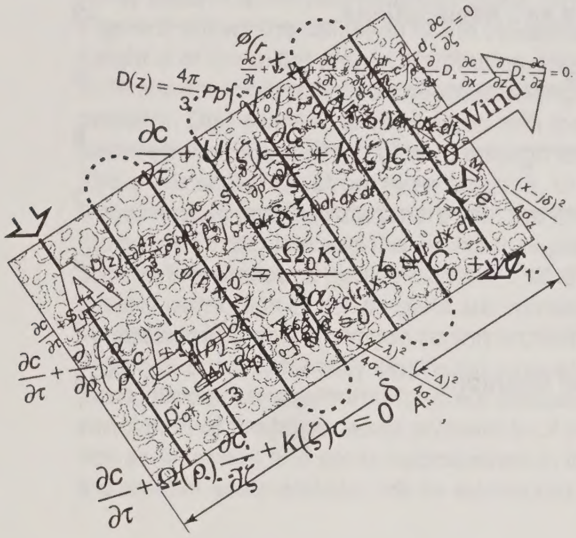

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Introduction

A typical pesticide spray pattern over a forest in uniform terrain is depicted in Figure 1, where *A* is the target area and the lines represent the flight path of the pesticide application aircraft. The aircraft creates trailing vortices, which greatly influence the initial state of the droplets. We assume here that these vortices have decayed. As the pesticide aerosol evaporates, the changing size of the droplets and their changing aerodynamics can be characterized. Depending on the dispensing nozzle and initial vortex mixing, there will be a characteristic droplet size distribution over a given initial volume; the larger droplets will separate from the smaller ones, spatiotemporally altering the droplet size distribution. Consider a spatiotemporally varying droplet distribution $c\ (r, x, z, t)$, where r denotes the radius of the droplets, x is the streamwise (with the wind) space variable, z is the vertical space variable, and t is time. The problem may be generalized to include a third space variable y and corresponding velocity V, to admit the situation where the spray pattern is not perpendicular to the wind direction. Figure 2 shows the definition of the variables relating to height Δ of the initial droplet distribution, tree height H, and δ. There are inherently two streamwise length scales in this problem. One scale, δ, is associated with the distance between each pass of the aircraft through the target region. The other scale, the streamwise length δ_A of the entire target region, is associated more with the off-target drift of the smallest droplets and the pesticide vapor. For an appropriate choice of spray nozzle and wind conditions, the greater proportion of the droplets are immobilized in the vegetation in a very restricted region around the area *A* in Figure 3, but a potentially significant amount of off-target pesticide can be windborne for great distances. The simulation of the larger scale problem is of importance in risk assessment and spray optimization; in this paper only the smaller scale problem will be addressed directly.

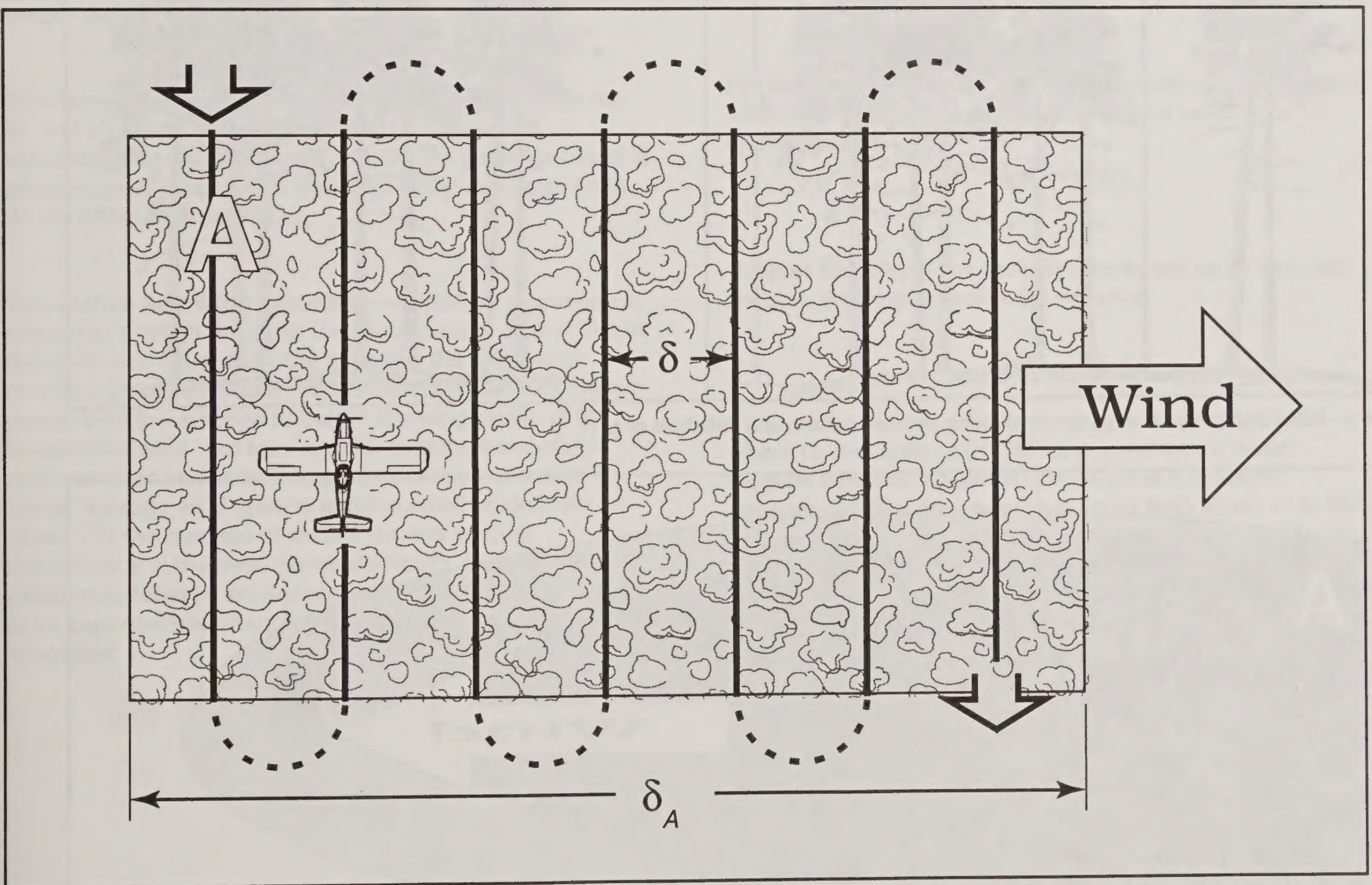

Figure 1—Aerial pesticide application pattern over forest area "A," showing definition of distances δ, δ_A.

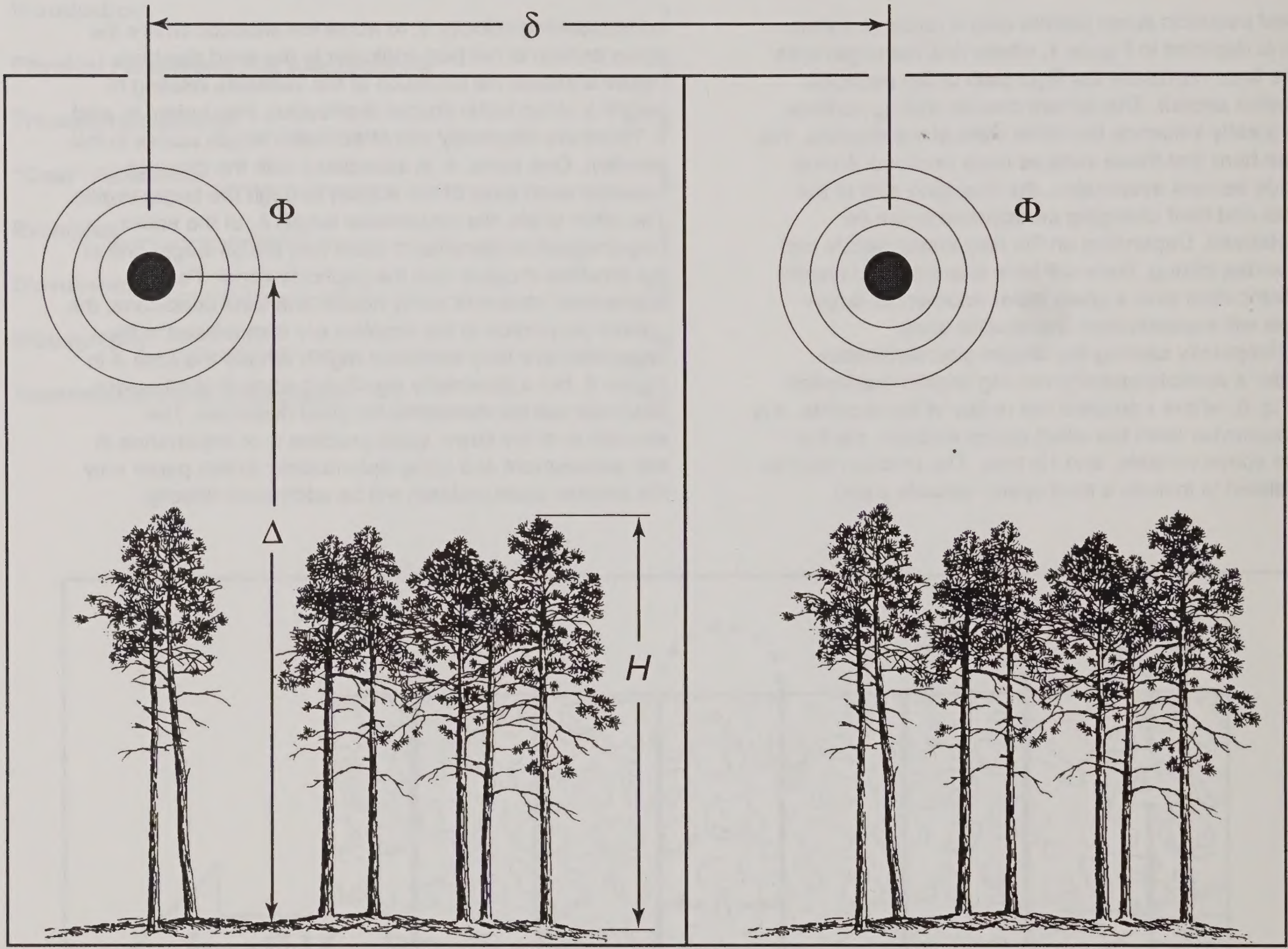

Figure 2—Initial distribution Φ of pesticide showing periodic pattern and definition of Δ, *H*, δ.

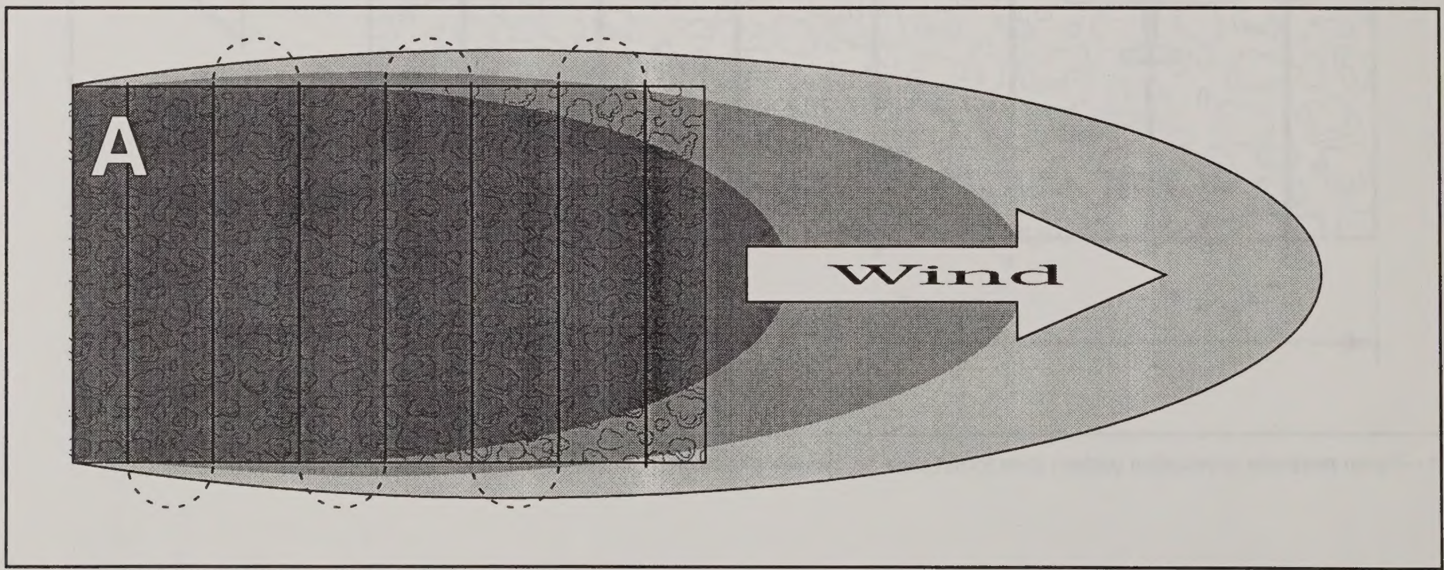

Figure 3—Off-target pesticide drift at three different times.

Physical Parameters and Assumptions

Saturation and Temperature—The results of a pesticide application can be affected by the ambient saturation and temperature, which in these models are taken to be constant through the vertical range, assuming that the spray is applied near the treetops. In pesticide evaporation models, a primary constant controlling the dynamics is

$$\alpha = \frac{S-1}{\dfrac{L^2 \rho_L}{K R_v T^2} + \dfrac{R_v T \rho_L}{D e_s(T)}}$$

(of units [r^2/f]) where S is saturation, L is latent heat of vaporization, ρ_L is liquid density, K is air thermal conductivity, R_v is the individual gas constant for the vapor, T is temperature, D is the diffusivity of the vapor, and e_s is the enthalpy. These parameters may be estimated from ambient conditions and thermodynamic relations for the pesticide evaporating in air. If the saturation $S>1$, we may expect condensation to be important; if $S<1$, we may expect evaporation to be important.

Dilution—The droplets are assumed dilute enough in the air that air velocities are unaffected by the droplet velocities, and droplets rarely collide. The pesticide vapor is also assumed dilute, such that local vapor concentrations do not affect the value of α.

Turbulence and Wind Velocities—Turbulent dispersion is neglected through dropping the second-order derivatives in the dynamics equations (that is, taking the Sherwood numbers to be infinite); the dispersion considered arises purely from the average turbulent shearing profile of the streamwise wind, and from droplet dynamics including sedimentation and evaporation. This is least accurate for higher average wind speeds and the smallest droplets or vapor. For the purpose of illustration, the vertical dependence of the average wind velocity is assumed to be reasonably fitted by an elementary function, here assumed to be exponentially changing to a constant as height increases:

$$U(z) = U_\infty\left(1 - e^{-\mathrm{K}z}\right) \tag{1}$$

Droplet Deposition onto Foliage—Although the deposition of droplets onto foliage is radius-dependent over the range of interest, it is assumed here to be dependent only on the vertical spatial coordinate. The rate of loss of droplet concentration to deposition is assumed to have a linear dependence on droplet concentration. The deposition coefficient is assumed to vary directly with foliage density. We assume a simple form

$$k(z) = k_o e^{-\gamma z} \tag{2}$$

where k_o has units [*1/f*].

Droplet Evaporation—The derivative *dr/dt* describes the change in droplet radius with time due to evaporation (or condensation), and is approximately given by [1, 2] (ignoring the ventilation factor),

$$r\frac{dr}{dt} = \alpha\left(1 - \frac{\beta}{r} + \frac{\gamma}{r^3}\right)$$

For large radius droplets this can be simplified, disregarding solution and curvature effects, to yield the usual approximation

$$r^2 = r_0^2 + 2\alpha t. \tag{3}$$

Droplet Velocity—The vertical velocity will be considered linear in the droplet radius dependence

$$\Omega(r) = \Omega_0 r \tag{4}$$

where Ω_0 has units [z/(rt)]. More accurately, for water droplets between 10 and 40 μm, there is a quadratic dependence; the dependence is linear from about 40 to 600 μm, and then proportional to $r^{1/2}$ for larger droplets. These nonlinear deviations are assumed negligible.

Transport Equations

The transport model for the droplet concentration $c\,(r, x, z, t)$, of units (droplets/unit volume) is:

$$\frac{\partial c}{\partial t} + \mathbf{v} \cdot \nabla c + \frac{\partial q}{\partial t} + \frac{\partial}{\partial r}\left(\frac{dr}{dt} c\right) - \frac{\partial}{\partial x} D_x \frac{\partial c}{\partial x} - \frac{\partial}{\partial z} D_z \frac{\partial c}{\partial z} = 0. \tag{5a}$$

Here D_i are the droplet turbulent dispersion parameters, and q is the concentration of deposited droplets within the vegetative canopy.

The vapor concentration, $C_v(x, z, t)$ (of units [mass/unit volume]), from evaporated pesticide satisfies

$$\frac{\partial c_v}{\partial t} + \mathbf{v} \cdot \nabla c_v + I_c(x,z,t) + I_q(x,z,t) + I_s(x,z,t) - \frac{\partial}{\partial x} D_x \frac{\partial c_v}{\partial x} - \frac{\partial}{\partial z} D_z \frac{\partial c_v}{\partial z} = 0 \tag{5b}$$

where I_c, I_q, I_s are source contributions from free droplets, deposited droplets, and infinitesimal droplets (from the edge of the droplet spectrum) respectively. These source terms are here assumed to satisfy

$$\frac{\partial I_c}{\partial t} = 4\pi\alpha\sigma \int_0^\infty r' c(r', x, z, t)\, dr', \tag{6a}$$

$$\frac{\partial I_q}{\partial t} = 4\pi\alpha\sigma \int_0^\infty r' q(r', x, z, t)\, dr', \tag{6b}$$

$$I_s = \lim_{r \to 0}\left[\frac{\alpha}{r} c(r, x, z, t)\right]. \tag{6c}$$

The parameter σ is the conversion factor of mass of vapor created per unit volume of liquid evaporated, and is specific to the pesticide and temperature. Equation (6*b*) reflects the simplifying assumption that deposited droplets have surface area as if they are spherical and entirely exposed to the air.

Under the given assumptions the droplet equation (5*a*) is

$$\frac{\partial c}{\partial t} + U_\infty\left(1 - e^{-Kz}\right)\frac{\partial c}{\partial x} + \Omega_0 r \frac{\partial c}{\partial z} + k_0 e^{-\gamma z} + \frac{\partial}{\partial r}\left(\frac{\alpha}{r} c\right) = 0. \tag{7}$$

The total droplet number loss from the target area defined by $c(r, x, z) \in [0, \infty]\mathrm{x}[0, \delta]\mathrm{x}[0, \infty]$ is characterized by the change of

$$M(t) = \int_0^\infty \int_0^\delta \int_0^\infty c(r, x, z)\, dz\, dx\, dr; \tag{8}$$

the loss fluxes can be calculated from integration of (7) over $c(r, x, z)$ (not including diffusive fluxes):

$$\frac{dM}{dt} = \int_0^\infty \int_0^\infty \left(\frac{\alpha c}{\rho}\right|_{r \to 0} dz\, dr - \int_0^\infty \int_0^\infty (Uc|_{x=\delta}\, dz\, dr + \int_0^\infty \int_0^\delta (\Omega c|_{z=0}\, dx\, dr, \tag{9}$$

that is, from the edge of the droplet spectrum, the horizontal drift, and sedimentation to the soil, respectively.

All the vapor can be considered to be mass lost "off target," calculated as a total from (6*a*, 6*b*, 6*c*)

$$V_{OT} = \int_0^\infty \int_0^\infty \int_0^\delta \left(I_{OT}^c + I_{OT}^q + I_{OT}^s\right) dx\, dz\, dt \tag{10a}$$

because it is assumed not to be deposited in the foliage. Similarly to the terms in (9), other mechanisms whereby pesticide mass can be off target are from droplets drifting out of the target region, whether horizontal loss

$$D_{OT}^h = \frac{4\pi}{3}\rho_p \int_0^\infty \int_0^\infty \int_0^\infty r^3 c(r,\delta,z,t)\, dr\, dz\, dt \tag{10b}$$

or vertical loss

$$D_{OT}^v = \frac{4\pi}{3}\rho_p \int_0^\infty \int_0^\delta \int_0^\infty r^3 c(r,x,0,t)\, dr\, dx\, dt \tag{10c}$$

where ρ_p is the liquid pesticide density, and diffusive flux has been excluded.

In order to set the problem in perspective, the second-order equation (5*a*) is cast also in its dimensionless form:

$$\frac{\partial c}{\partial \tau} + S_U^{-1}\left(1-e^{-K\zeta}\right)\frac{\partial c}{\partial \xi} + S_\Omega^{-1}\rho\frac{\partial c}{\partial \zeta} + S_\alpha^{-1}\frac{\partial}{\partial \rho}\left(\frac{c}{\rho}\right) + e^{-K\zeta}c - \frac{\partial}{\partial \xi}d_\xi\frac{\partial c}{\partial \xi} - \frac{\partial}{\partial \zeta}d_\zeta\frac{\partial c}{\partial \zeta} = 0 \tag{11}$$

where $d_\xi = D_\xi/\delta^2 k_0$ is the inverse effective horizontal Sherwood number, $d_\zeta = D_\zeta/H^2 k_0$, is the inverse effective vertical Sherwood number, $\tau = t/k_0$, $\xi = x/\delta$, $\zeta = z/H$, $\rho = r/r_{max}$ where r_{max} is the approximate maximum size of droplet (always limited by breakup instability), and the Stanton numbers are $S_U = \delta k_0/U_\infty$ (horizontal), $S_\Omega = Hk_0/(\Omega_0 r_{max})$ (vertical), and S_α (evaporative). Other dimensionless numbers of importance are δ/H and $\varepsilon = \Omega_0/U_\infty$.

There are various parameter limits of physical interest, namely Sherwood numbers $Sh_t \to 0, \infty$ and velocity ratios $\varepsilon \to 0, \infty$. The hyperbolic problems considered here all satisfy $Sh_t \to \infty$, appropriate for ballistic and almost ballistic droplets. Also, we consider $\Delta/H \approx 2$, illustrating a case where the aircraft has flown fairly close to the canopy height.

Boundary and initial conditions for the hyperbolic equation (7) are $c \to 0$ for $x = \pm\infty$, and $c\,(r, x, z, 0) = \phi(r, x, z)$. Specifically, the initial condition can be modeled as

$$\phi(\mathrm{r},\mathrm{x},\mathrm{z}) = \mathrm{A} r^n e^{-br-\frac{(z-\Delta)^2}{4\sigma_z}} \sum_{j=0}^{\mathrm{M}} e^{-\frac{(x-j\delta)^2}{4\sigma_x}},$$

but in the examples below we focus on the cloud of pesticide from only one pass of the aircraft, given in the form

$$\phi(\mathrm{r},\mathrm{x},\mathrm{z}) = \mathrm{A} r^n e^{-br-\frac{(x-\lambda)^2}{4\sigma_x}-\frac{(z-\Delta)^2}{4\sigma_z}}, \tag{12}$$

or, undimensionalized,

$$\phi(\rho,\xi,\zeta) = \tilde{\mathrm{A}}\rho^n e^{-B\rho-\frac{(\xi-\lambda/\delta)^2}{4\sigma_\xi}-\frac{(\varsigma-\Delta/H)^2}{4\sigma_\varsigma}}. \tag{13}$$

This is in accordance with reducing the number of possible solutions to the optimization problem, disregarding diffusive transport, and is consistent with keeping the choice of U_∞ to a relatively small value for pilot safety and reduction of off-target drift and off-target deposition. We take σ_ξ, σ_ζ, k_0 to be fixed; but more generally the adjustable parameters for optimization include n, b, A, Δ, δ, U_∞, α, and k_0.

"Cost" Functions

In order to specify an optimization problem, one must characterize a notion of "how close to optimum" a particular solution is. With this in mind, introduce a function $P=P(z)$, which is the average (measured or theoretical) distribution of pests in the foliage. Some pests are concentrated in low bushes, while others are concentrated in the upper foliage of trees.

The function P can then be compared to an average dosage measure $D(z)$ by a "mortality" function $M(z)=aP(z)$, simply proportional to P and indicating the desired pesticide mass dosage according to pest distribution and pesticide efficacy. D is calculated relative to a particular solution to the transport equations:

$$\mathrm{D}(z) = \frac{4\pi}{3}\rho_p \int_0^\infty \int_0^\delta \int_0^\infty r^3 q(r,x,z,t)\,dr\,dx\,dt.$$

The comparison

$$C_0(D) = \int_A (\mathrm{M}(z) - D(z))^2\,dz \qquad (14)$$

then can be minimized with respect to whatever free parameters appear in $D(z)$. Typically, one must solve the optimization problem numerically.

An important consideration is that of the off-target pesticide. Two major off-target effects are possible:

- If the pest is only in the vegetation, then pesticide reaching the soil is off target.
- Pesticide drifting horizontally may reach locations outside the prescribed application area.

Whether or not the "on-target" cost function C_0 is minimized, the off-target drift may be large or small, and might itself need to be minimized, particularly if the pesticide is noxious. If the off-target drift is to be minimized, then for a particular solution, we calculate off-target dosage D_{OT} as in (10), which might include both adsorbed and unadsorbed pesticide, perhaps including soil uptake and vapor production, and minimize

$$C_1 = D_{OT}^h + D_{OT}^v + V_{OT}. \qquad (15)$$

To simultaneously minimize on-target dosage error and off-target drift, one may define a "penalty function'" L and "penalty" γ such that

$$L = C_0 + \gamma C_1.$$

The penalty γ can be adjusted to change the relative weight of importance of the two cost functions C_0 and C_1.

Examples

In this section we consider some aspects of the pesticide application problem. (Analytical results are listed in the appendix.) Figures 4 and 5 show the evolution of an initially symmetric droplet profile, including free and deposited droplets. In Figure 4, the horizontal Stanton number S_u is large, while in Figure 5 it is small, showing more of an effect of the shearing wind. If we look at the total pesticide mass deposited as only a function of ζ, as in Figure 6, increasing S_u shifts the peak deposition higher in the foliage, demonstrating a way to determine the shape of deposition profile to fit a desired dosage profile. The ratio of velocities ε may be chosen to isolate most of the deposited pesticide mass within the target subregion, as Figure 7 demonstrates. In any case, one must calculate the pesticide loss by the various possible mechanisms. Figure 8 shows the flux of mass loss at the horizontal and vertical boundaries, at various values of ε, showing a high degree of "controllability" of the relative losses through ε. Pesticide mass loss through mechanisms of vapor production is shown in Figure 9, including vapor from the droplet spectrum edge, deposited droplets, and free droplets.

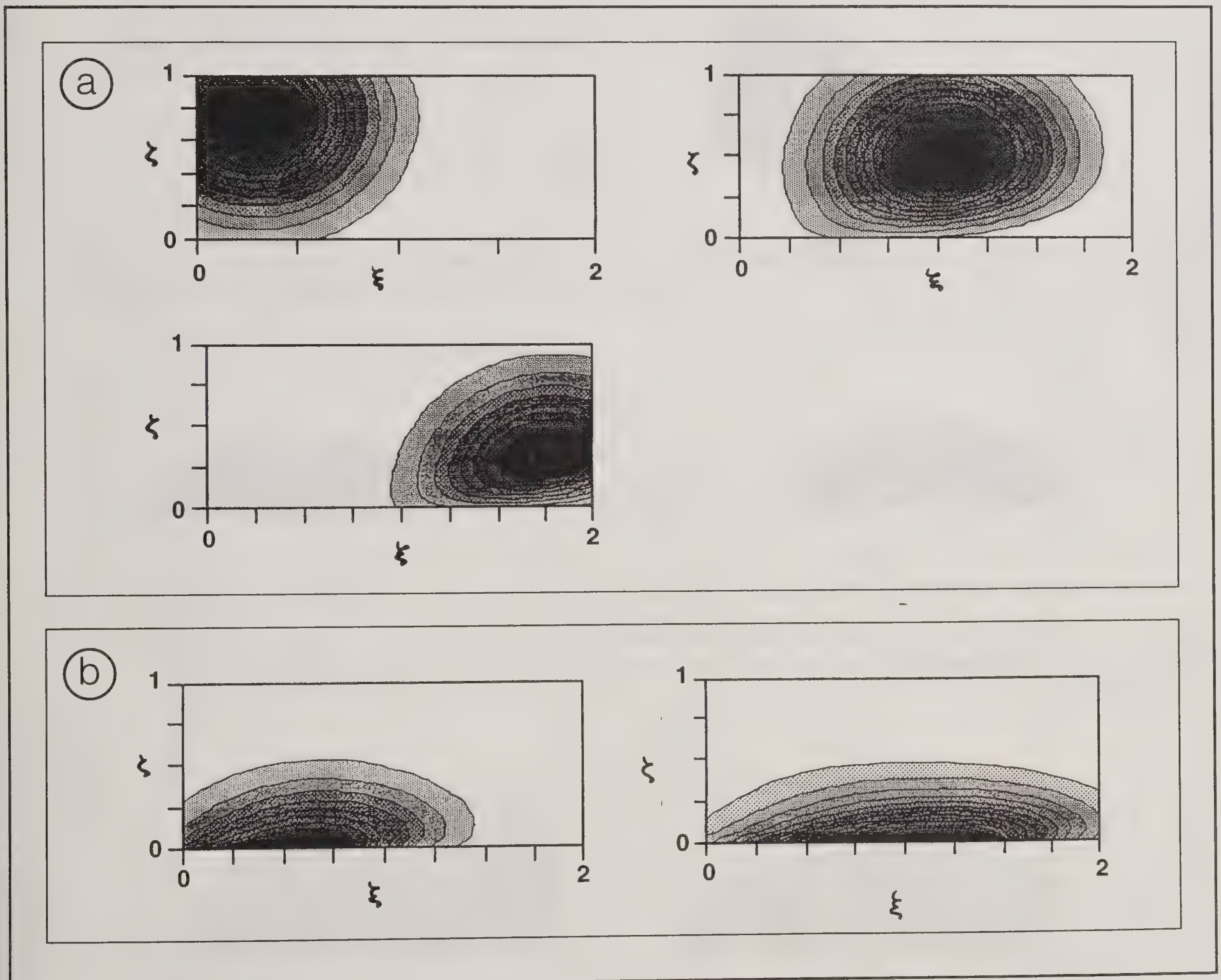

Figure 4—Solution of (7) at three successive times, showing (a) free droplet concentration and (b) deposited droplet concentration. Here S_u is relatively high.

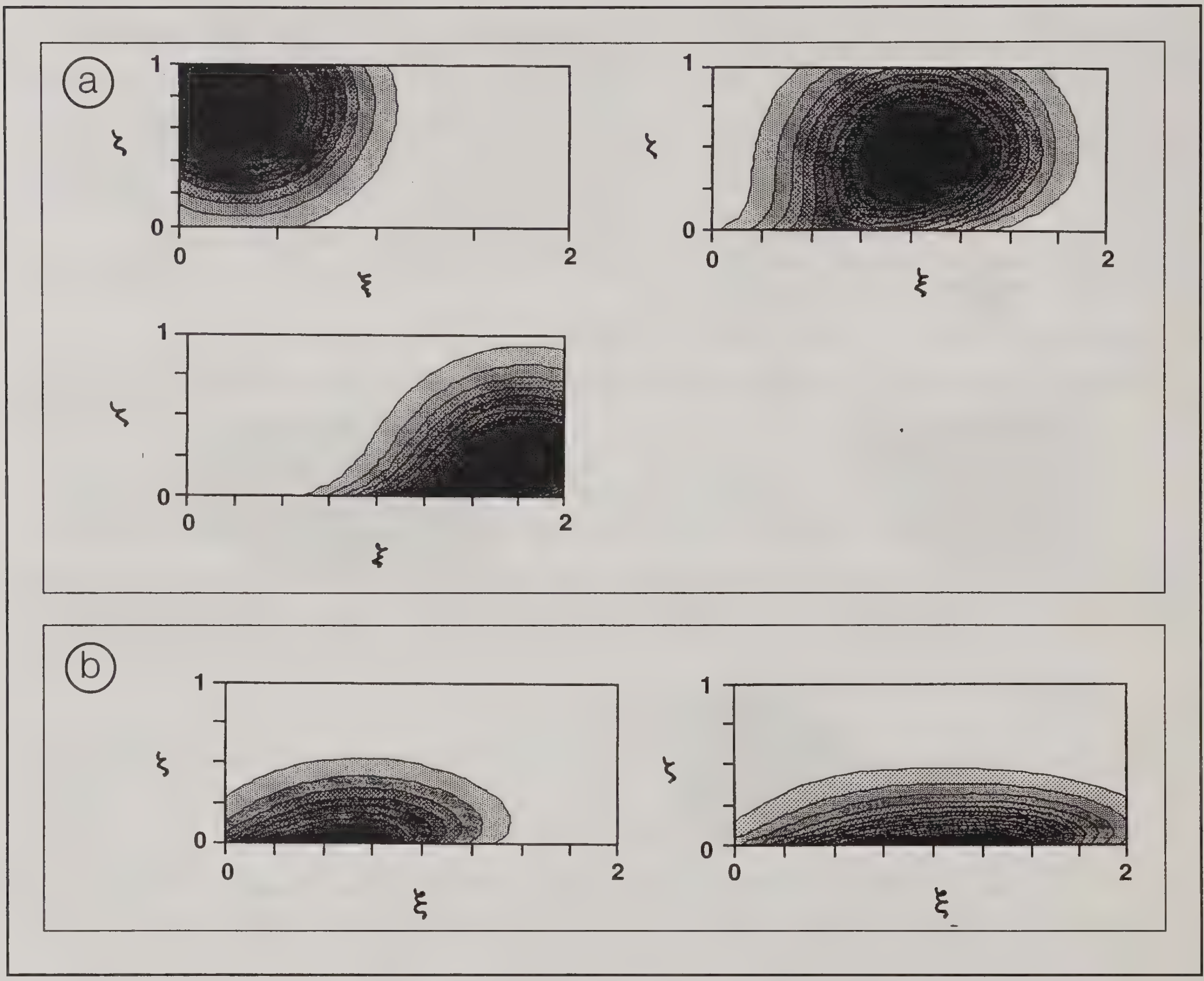

Figure 5—Solution of (10) at three successive times, showing (a) free droplet concentration and (b) deposited droplet concentration. Here S_u is relatively low.

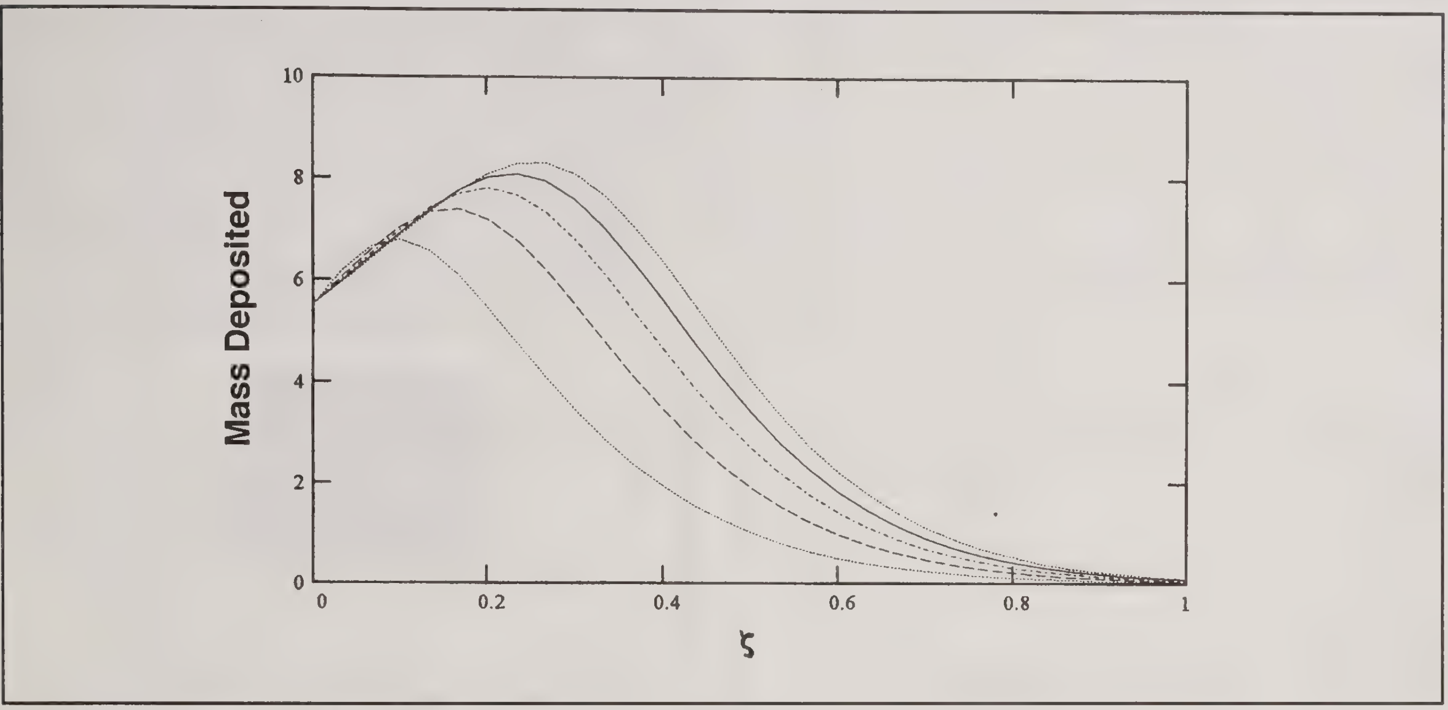

Figure 6—For increasing S_{υ}, the peak deposition shifts higher into the foliage.

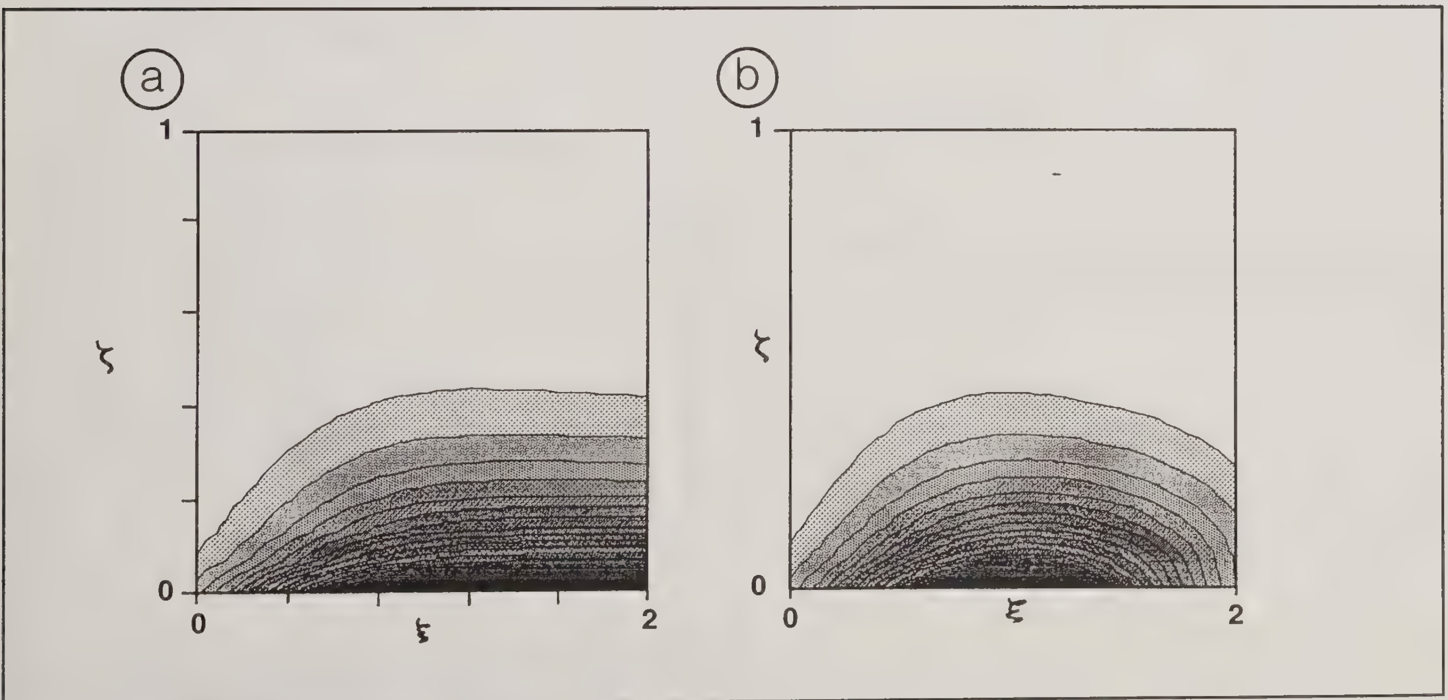

Figure 7—Deposited droplet concentration at (a) $\Omega_o << U_\infty$ and (b) $\Omega_o >> U_\infty$.

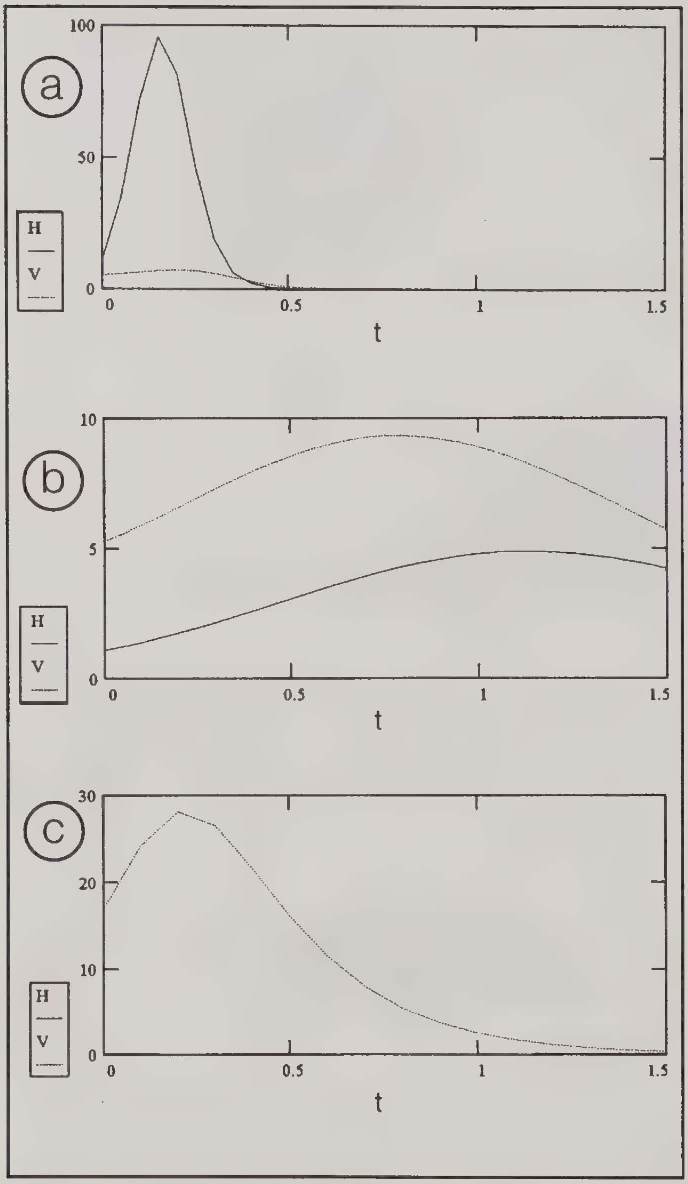

Figure 8—Mass loss flux at horizontal (-) and vertical (....) boundaries through time: (a) $\Omega_0 << U_\infty$, (b) $\Omega_0 \approx U_\infty$, and (c) $\Omega_0 >> U_\infty$.

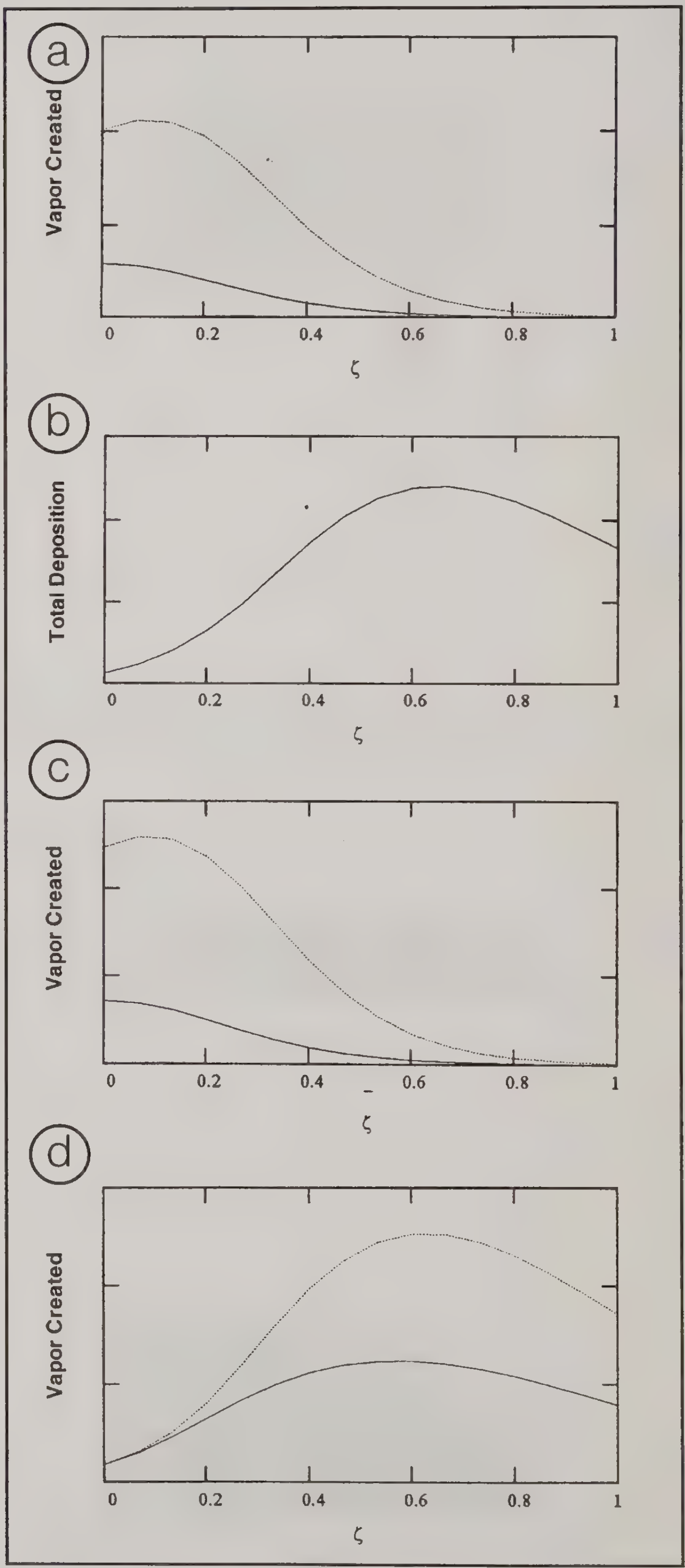

Figure 9—(a) Total vapor mass production from droplet spectrum edge $r \rightarrow 0$ at two successive times, (b) mass deposition at two successive times, (c) mass of vapor created from deposited droplets at two successive times, and (d) mass of vapor created from free droplets at two successive times.

Finally, one may investigate the effects of varying the spray nozzle, assuming a continuously distributed choice of nozzle types based on the initial condition parameter n (Figure 10a; see Equation 13). If one has a desired dosage profile $D(\zeta)$ as shown by the dashed curve in Figure 10c, one may calculate the foliage deposition corresponding to each possible n, and compare each resultant deposition profile with D using Equation 14. Figure 10c shows two nearly optimal profiles, varying n as the control parameter.

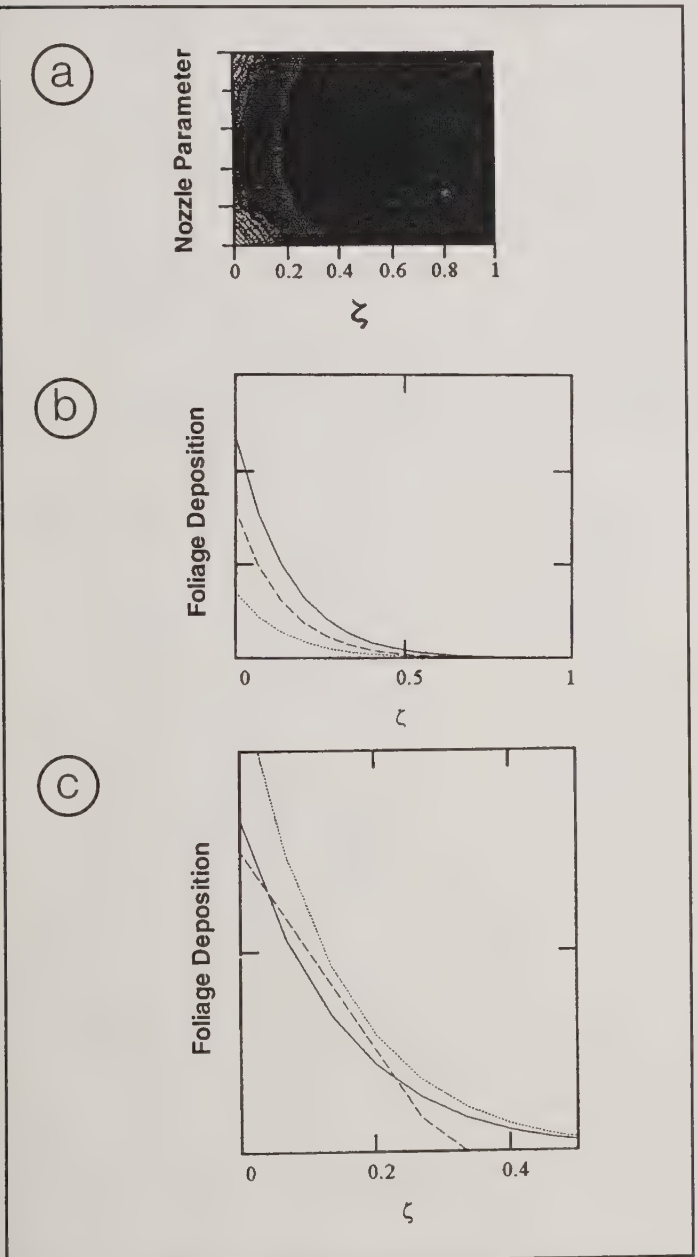

Figure 10—(a) Effect of initial conditions variation (due to nozzle type) on deposition profile. (b) Resultant dosages for three different values of n. (c) Calculated deposition profiles near to desired deposition (dashed curve).

Discussion

In this paper we have introduced a preliminary quantitative dynamic model for investigating how to optimize the aerial application of pesticide to a forest, identifying the various control parameters and their effects. By disregarding the second-order terms in the dynamic equations one may obtain useful, practical solutions.

Bibliography

Fuchs, N. 1989. The mechanics of aerosols. Mineola, NY: Dover.

Kracke, R.; Puckett, J. 1964. Journal of Colloid Science. 19: 765.

Matveev, L. 1984. Cloud dynamics. Boston: D. Reidel Publishing Co.

Pruppacher, H.; Klett, J. 1978. Microphysics of clouds and precipitation. Boston: D. Reidel Publishing Co.

Reist, P. 1993. Aerosol science and technology. 2nd ed. New York: McGraw Hill.

Rogers, R. 1976. A short course in cloud physics. New York: Pergamon Press.

Appendix: Analytical Solutions

All analytical solutions are calculated by the method of characteristics.

For the case of only evaporation and deposition, but no movement of the cloud, that is, $\Omega=0$, $U_\infty=0$, $\varepsilon=0$

$$\frac{\partial c}{\partial \tau}+\frac{\partial}{\partial \rho}\left(\frac{\alpha}{\rho}c\right)+k(\zeta)c=0$$

which gives the solution

$$\frac{\rho}{\sqrt{\rho^2-2\alpha\tau}}\phi\left(\sqrt{\rho^2-2\alpha\tau},\zeta\right)e^{-k(\zeta)\tau}.$$

Only considering streamwise pesticide movement and foliage deposition, that is, $\Omega_0=0$, $\varepsilon=0$, $\alpha=0$, we have

$$\frac{\partial c}{\partial \tau}+U(\zeta)\frac{\partial c}{\partial \xi}+k(\zeta)c=0$$

so

$$c(\xi,\zeta,\tau)=\phi(\xi-U(\zeta)\tau,\zeta)e^{(-k(\zeta)\tau)}.$$

Thus the deposition rate in the foliage is given by

$$\frac{\partial q}{\partial t}=k(\zeta)c(\xi,\zeta,\tau)$$

or

$$q(\xi,\zeta,\tau)=k(\zeta)\int_0^\tau\phi(\xi-U(\zeta)\tau',\zeta)e^{(-k(\zeta)\tau')}d\tau'$$

and so the total deposition $D(\xi, \zeta)$ is

$$D(\xi,\zeta)=\int_0^\infty q\,d\tau.$$

For the case of no evaporation and no streamwise transport, that is, $\alpha=0$, $U_\infty=0$,

$$\frac{\partial c}{\partial \tau}+\Omega(\rho)\frac{\partial c}{\partial \zeta}+k(\zeta)c=0$$

so we have

$$c(\rho,\zeta,\tau)=\phi(\rho,\zeta-\Omega(\rho)\tau)e^{(\varphi)}$$

where

$$\varphi=\frac{\beta}{\gamma\Omega(\rho)}\left(e^{-\gamma(\zeta-\Omega(\rho)\tau)}-e^{-\gamma\zeta}\right).$$

For evaporation with sedimentation, that is, $\alpha<0$, $U_\infty=0$,

$$\frac{\partial c}{\partial \tau}+\frac{\partial}{\partial \rho}\left(\frac{\alpha}{\rho}c\right)+\Omega(\rho)\frac{\partial c}{\partial \zeta}+k(\zeta)c=0$$

so

$$c(\rho,\zeta,\tau)=\frac{\rho}{\sqrt{\rho^2-2\alpha\tau}}\phi\left(\sqrt{\rho^2-2\alpha\tau},\zeta-\frac{\Omega_0\rho^3}{3\alpha}+\frac{\Omega_0}{3\alpha}\left(\rho^2-2\alpha\tau\right)^{\frac{3}{2}}\right)e^{\Phi}$$

where

$$\Phi=-\frac{k_0}{3\alpha\nu^{2/3}}e^{-\tau\zeta+\frac{\Omega_0\gamma}{3\alpha}\rho^3}\int_{\nu(\rho^2-2\alpha\tau)^{\frac{3}{2}}}^{\nu\rho^3}\sigma^{-\frac{1}{3}}e^{-\sigma}d\sigma$$

and

$$\nu=\frac{\Omega_0\gamma}{3\alpha}.$$

For the case of saturated conditions, sedimentation, and shearing flow, that is $\alpha=0$,

$$\frac{\partial c}{\partial \tau}+U(\zeta)\frac{\partial c}{\partial \xi}+\Omega(\rho)\frac{\partial c}{\partial \zeta}+k(\zeta)c=0$$

we obtain on the entire domain

$$c(\rho,\xi,\zeta,\tau)=\phi(\rho,\xi-U_\infty\tau-\Lambda,\zeta-\Omega(\rho)\tau)e^{(\varphi)},$$

where

$$\Lambda=\frac{1}{\kappa\Omega(\rho)}\left(U(\zeta-\Omega(\rho)\tau)-U(\zeta)\right)$$

and

$$\varphi=\frac{1}{\gamma\Omega(\rho)}\left(k(\zeta-\Omega(\rho)\tau)-k(\zeta)\right).$$

For the general hyperbolic problem,

$$\frac{\partial c}{\partial \tau}+U(\zeta)\frac{\partial c}{\partial \xi}+\frac{\partial}{\partial \rho}\left(\frac{\alpha}{\rho}c\right)+\Omega(\rho)\frac{\partial c}{\partial \zeta}+k(\zeta)c=0$$

so

$$c(\rho,\xi,\zeta,\tau)=\frac{\rho}{\sqrt{\rho^2-2\alpha\tau}}\phi\left(\sqrt{\rho^2-2\alpha\tau},\xi+\Lambda,\zeta-\frac{\Omega_0\rho^3}{3\alpha}+\frac{\Omega_0}{3\alpha}\left(\rho^2-2\alpha\tau\right)^{\frac{3}{2}}\right)exp(\Phi)$$

where

$$\Phi=-\frac{k_0}{3\alpha v^{2/3}}e^{-\gamma\zeta+\frac{\Omega_0\gamma}{3\alpha}\rho^3}\int_{v\left(\rho^2-2\alpha\tau\right)^{\frac{3}{2}}}^{v\rho^3}\sigma^{-\frac{1}{3}}e^{-\sigma}d\sigma$$

and

$$v=\frac{\Omega_0\gamma}{3\alpha}$$

and

$$\Lambda=-U_\infty\tau+U_\infty e^{-\kappa\zeta_0}\frac{\Omega_0\kappa}{3\alpha}\rho^3\int_{v_0\left(\rho^2-2\alpha\tau\right)^{\frac{3}{2}}}^{v_0\rho^3}\sigma^{-\frac{1}{3}}e^{-\sigma}d\sigma$$

with

$$v_0=\frac{\Omega_0\kappa}{3\alpha}$$

$$\zeta_0=\zeta-\frac{\Omega_0\rho^3}{3\alpha}+\frac{\Omega_0}{3\alpha}\left(\rho^2-2\alpha\tau\right)^{\frac{3}{2}}.$$

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Ammons, Richard; Thistle, Harold; Barry, Jack. 1996. Optimized pesticide application. Tech. Rep. 9634-2831-MTDC. Missoula, MT: U.S. Department of Agriculture, Forest Service, Missoula Technology and Development Center. 16 p.

An approach to the problem of modeling atmospheric transport and optimizing deposition of pesticide over and through a forest canopy is presented. The approach incorporates droplet evaporation, transport of the droplet cloud, foliage deposition, and a shearing wind profile. Significant dimensionless dynamic parameters are identified, including effective Sherwood numbers, Stanton numbers, a distance ratio, and a velocity ratio. Second-order dynamic terms in the transport equations are omitted; the resulting hyperbolic equations are appropriate for significant limiting conditions of the transport parameters, namely infinite Sherwood numbers. Such models prove useful in optimization of spray conditions, spray nozzles, and application techniques. Analytical solutions are given to the hyperbolic forms of the pesticide transport equations. The problem of optimizing the spray application with respect to adjustable parameters is described. Various examples are discussed.

Keywords: aerial application, aerial spraying, mathematical models.

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